Mixing Rates of Supercritical CO_2 with Brine in Deep Sedimentary Formations

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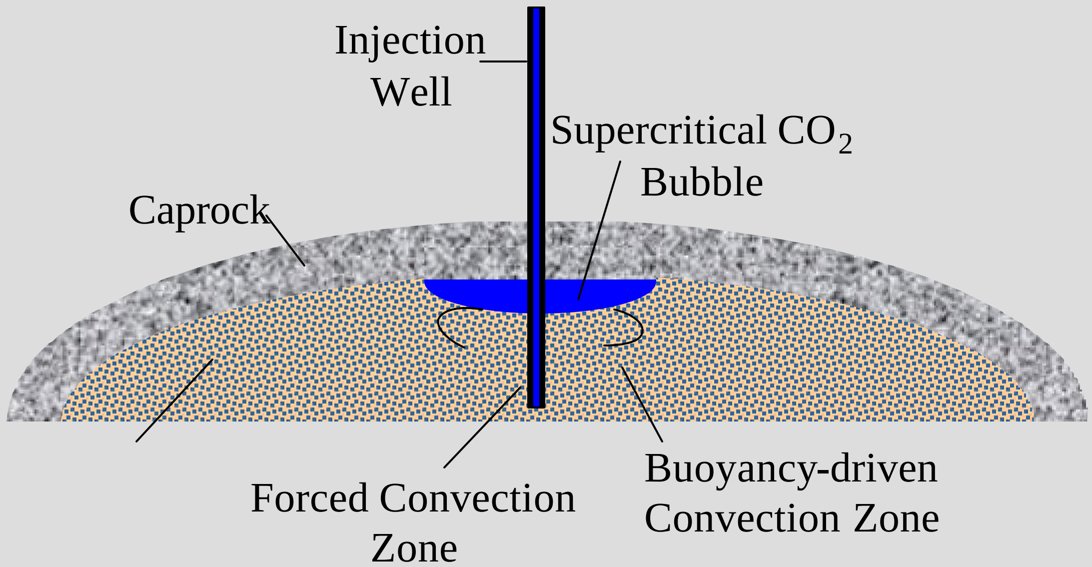
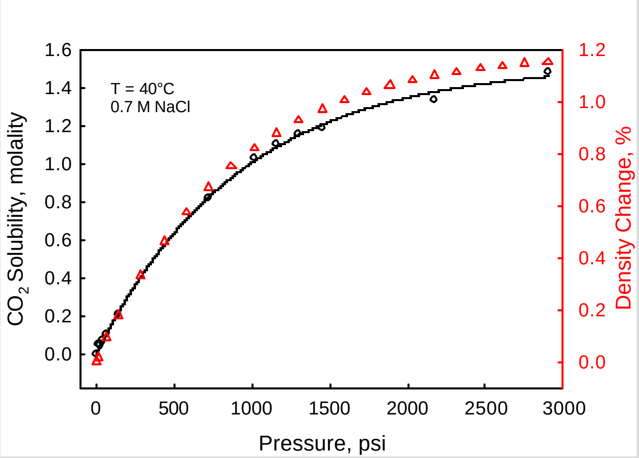
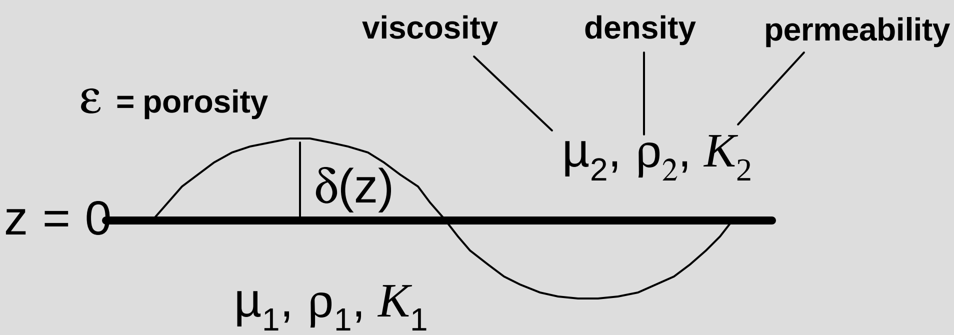
Injection Scenario for Deep Saline Formation





- Lower density of $scCO_2$ as compared with brine causes the injected CO_2 to float as a bubble restrained by low permeability caprock
- Area of review around well is determined by injection rate and rate of buoyancy-driven brine turnover
- Reduce time required for complete dissolution and mixing of the CO_2 into the formation brine

Perturbation Theory of Hydrodynamic Instability



$$\sigma = \frac{\varepsilon\left(\frac{\mu_1}{K_1}+\frac{\mu_2}{K_2}\right)}{2(\rho_1+\rho_2)}\left[\sqrt{1+\frac{8\pi g}{\varepsilon\,?}\,\frac{(\rho_2-\rho_1)(\rho_1+\rho_2)}{\left(\frac{\mu_1}{K_1}+\frac{\mu_2}{K_2}\right)^2}}-1\right]$$

perturbation wavelength

Linearized Perturbation Bernoulli Equations

$$\frac{1}{\varepsilon}\frac{\partial\varphi'}{\partial t}+\frac{P}{\rho_1}+\frac{\mu_1}{\rho_1 K_1}+gz=0$$

$$\frac{1}{\varepsilon}\frac{\partial\varphi'}{\partial t}+\frac{P}{\rho_2}+\frac{\mu_2}{\rho_2 K_2}+gz=0$$

If $\rho_2 > \rho_1$, $\sigma > 0$:

- system is unconditionally unstable
- perturbation grows with time

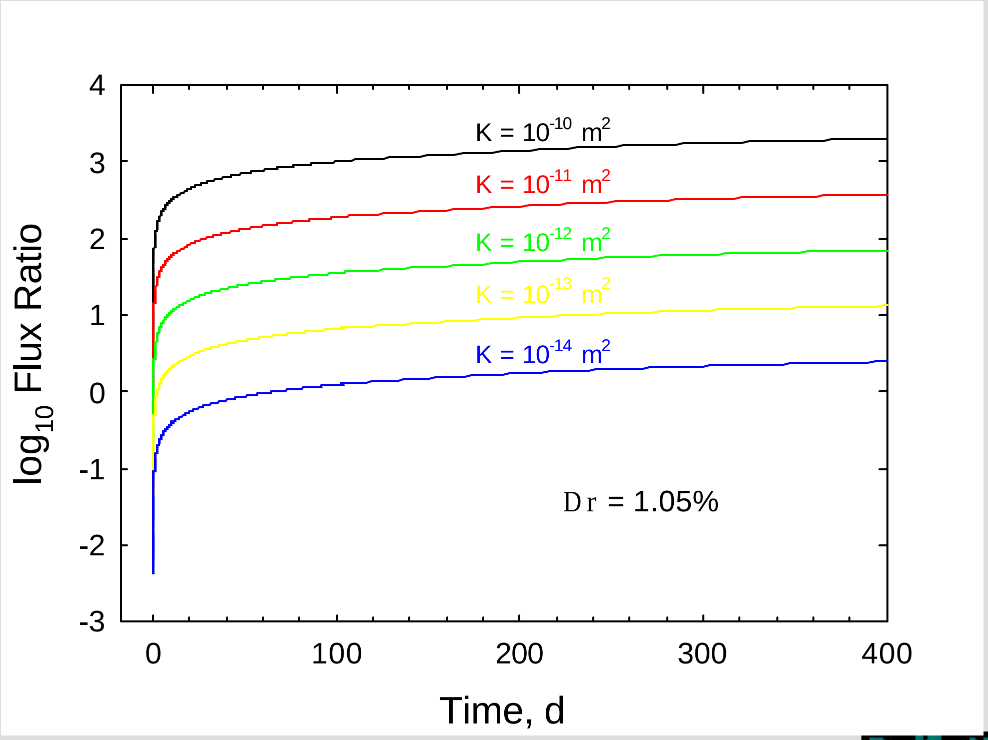
Perturbation wavelength will depend on structure, properties, and inhomogeneities in porous medium.

Propagation of Perturbation

<u>Finger Velocity</u>

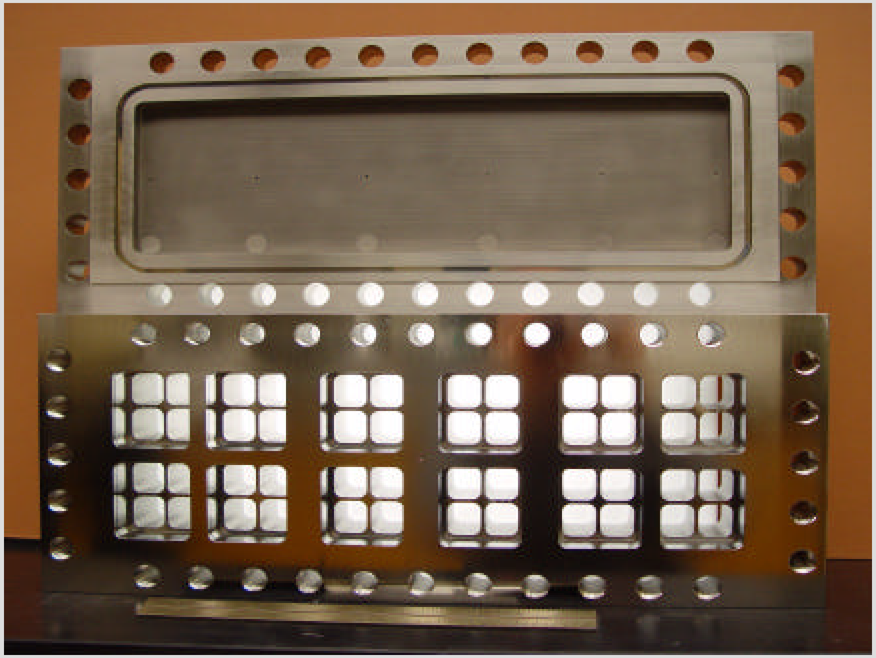
$$V_f = \beta \frac{(\rho_2 - \rho_1) g K}{\varepsilon \mu}$$

$$\frac{\text{Convective Flux}}{\text{Diffusive Flux}} = \frac{f_c \beta (\rho_2 - \rho_1) g K}{\varepsilon \mu \sqrt{\dfrac{4 \varepsilon D}{\pi t}}}$$



Experimental Challenges

- Large enough pressure cell to investigate mixing phenomena on a relevant scale
- Visual/spectroscopic interrogation of plume development
- Capability of operating for extended time periods with $SCCO_2$ and brine solutions



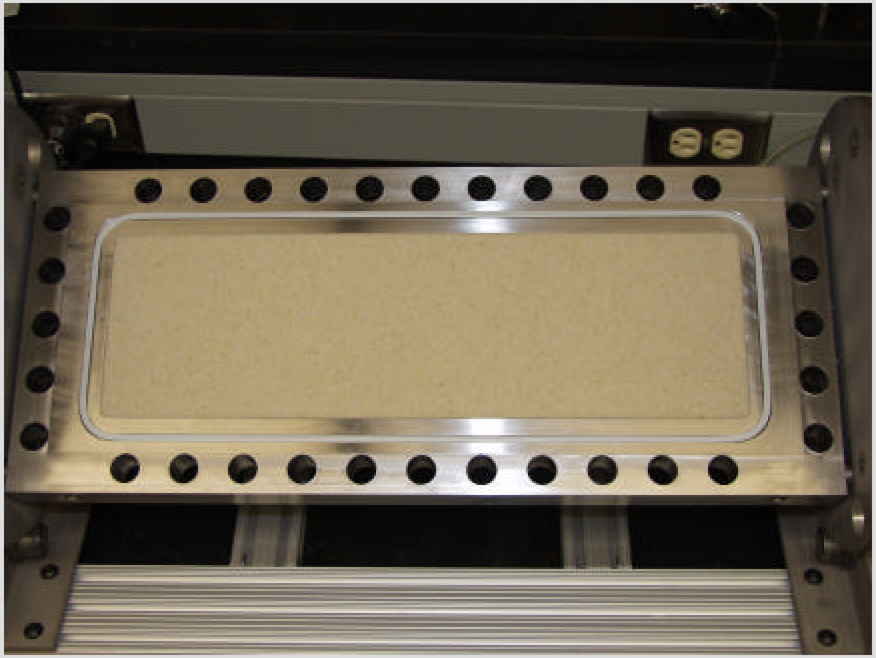
Cell dimensions: 45.4 cm (*length*) x 14.3 cm (*height*) x 1.27 cm (*depth*)

STOMP-CO_2 Simulator

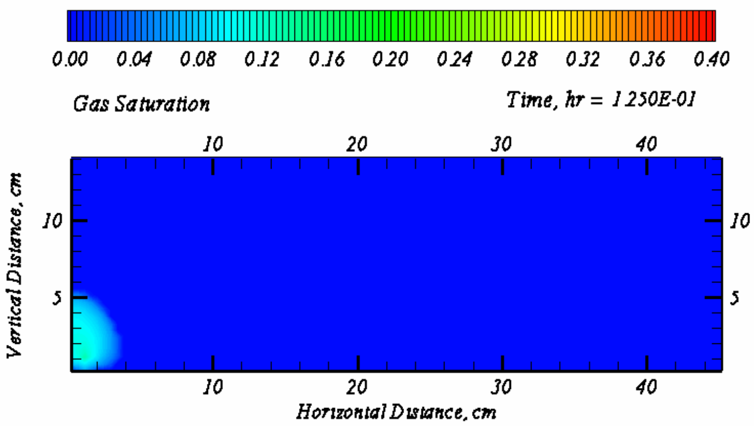
- H_2O-NaCl-CO_2-Energy and H_2O-NaCl-CO_2 operational modes of the STOMP simulator (*Subsurface Transport Over Multiple Phases)*
- Three mass constituents
  - *water, salt and carbon dioxide*
- Four phases
  - *aqueous, SCCO_2, precipitated salt, and geologic media*
- Complete EOS module
  - Physical properties (density, viscosity, etc.)
  - Transport properties (thermal conductivity, diffusion, permeability)
  - Thermodynamic properties (enthalpy, solubility, fugacity, Henry's constant)

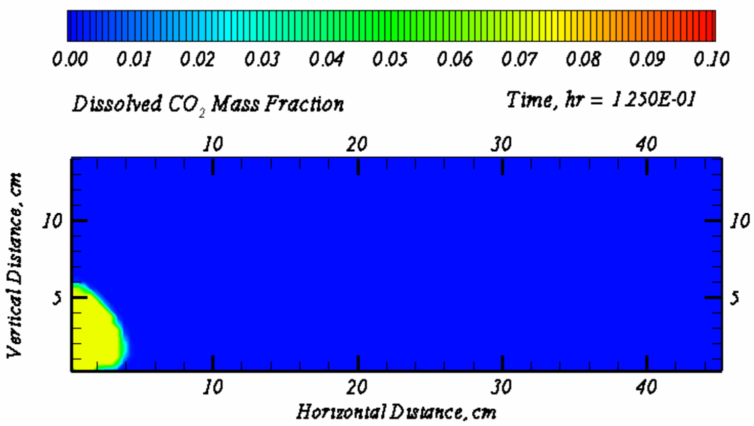
STOMP-CO_2 Simulation Parameters

- Initial conditions: 30/20 Accusand saturated with pure water, 13.8 MPa, 25°C
- Inflow port: Liquid CO_2 at 13.8 MPa, 25°C, 4.29 cm^3/min
- Outflow port: 13.8 MPa, 25°C
- Computational domain: 100 x 50 uniform grid cells 0.454 cm (length) x 0.286 cm (height) x 1.27 cm (width)

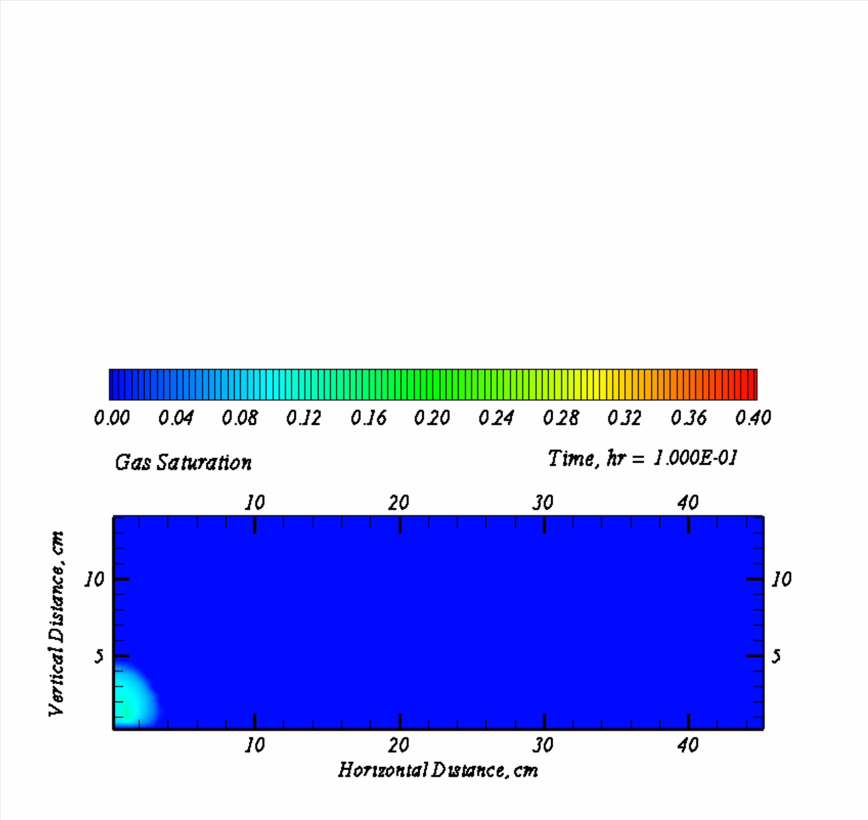


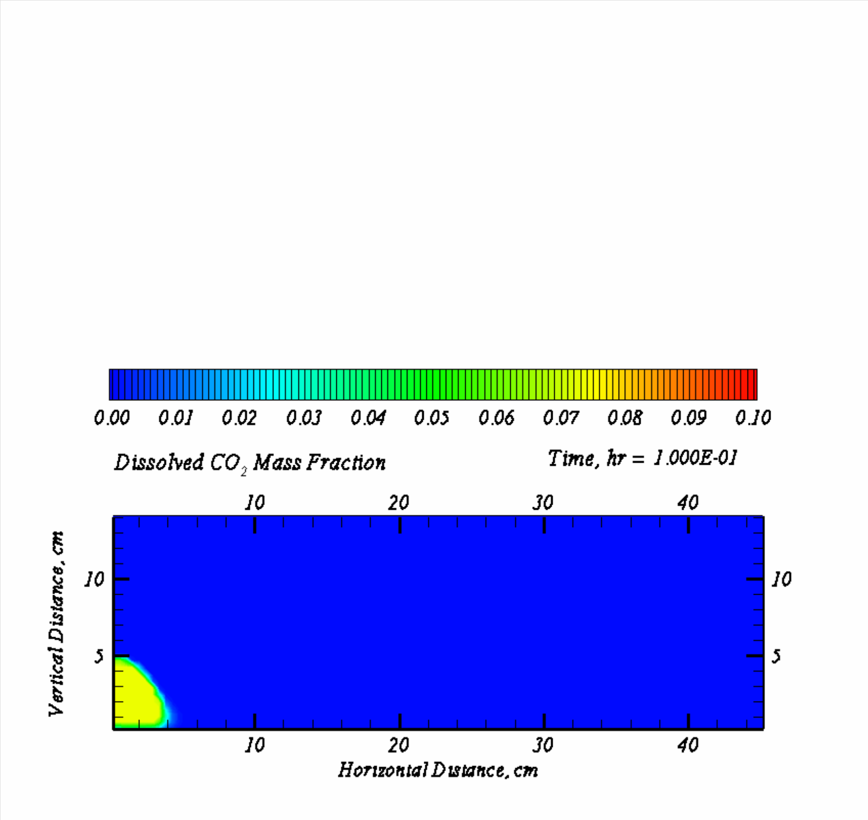
STOMP-CO_2 Simulation of Injection Experiment (No Density Dependence)



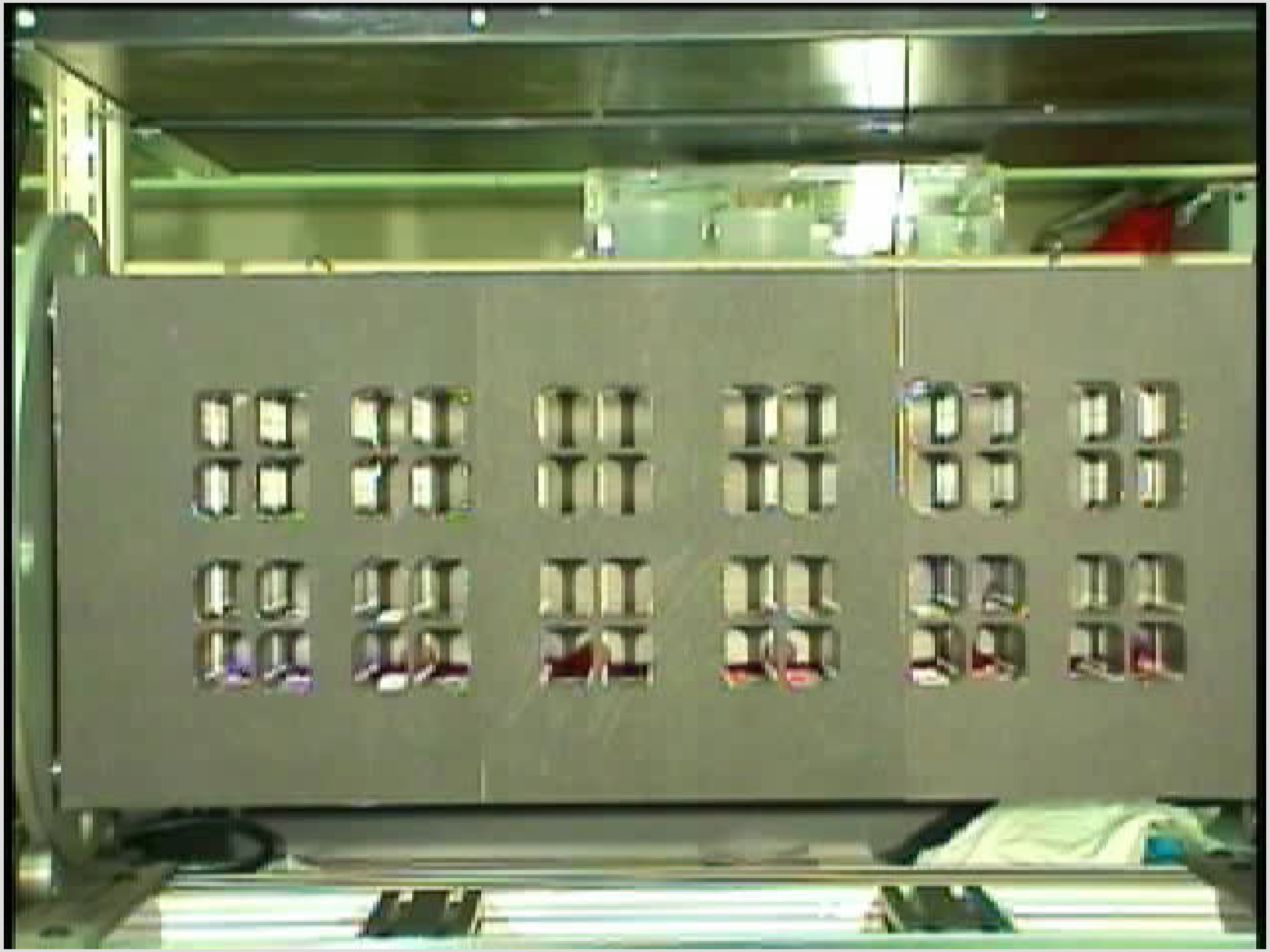


STOMP-CO_2 Simulation of Injection Experiment (With Density Dependence)

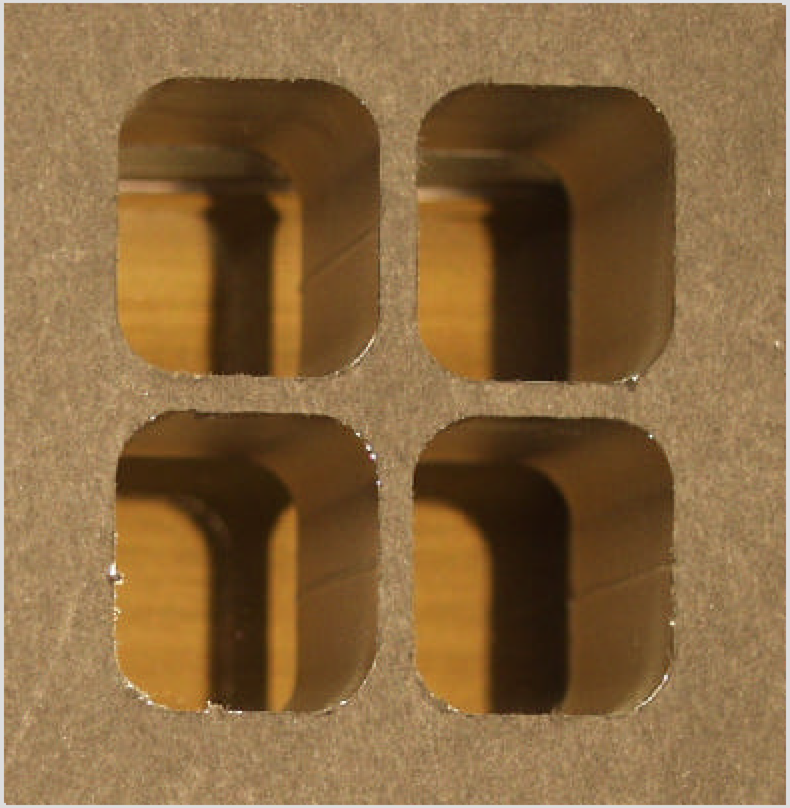


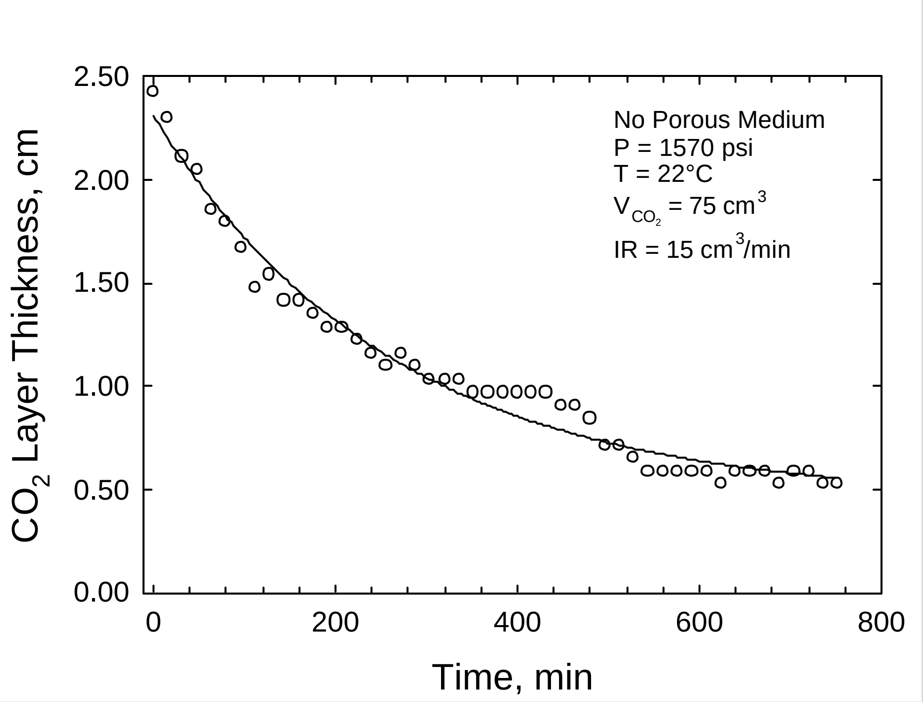


CO_2 Injection Test (No Porous Medium)

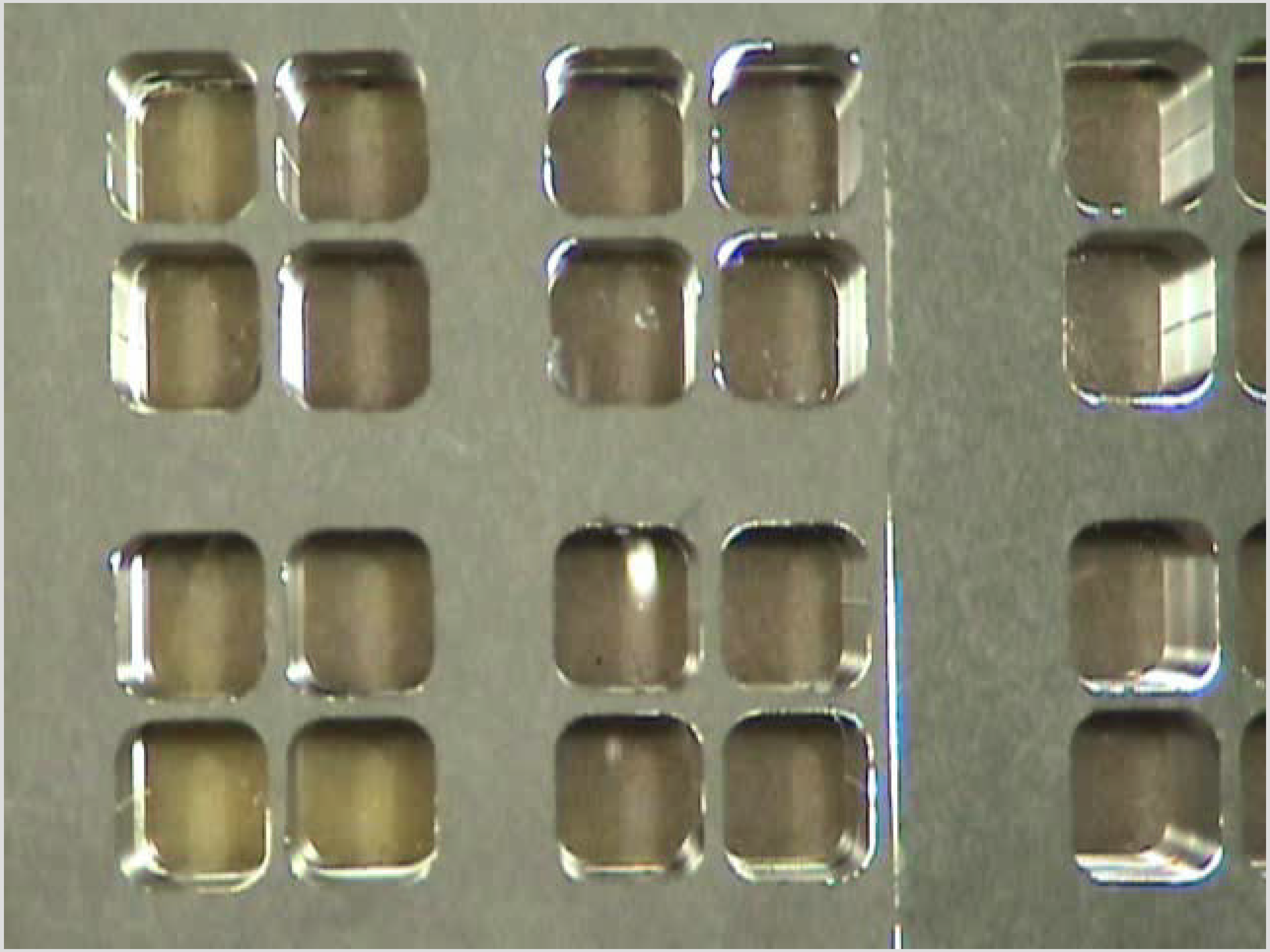


CO_2-H_2O Interface Tracking





CO_2 Injection Test (Accusand)



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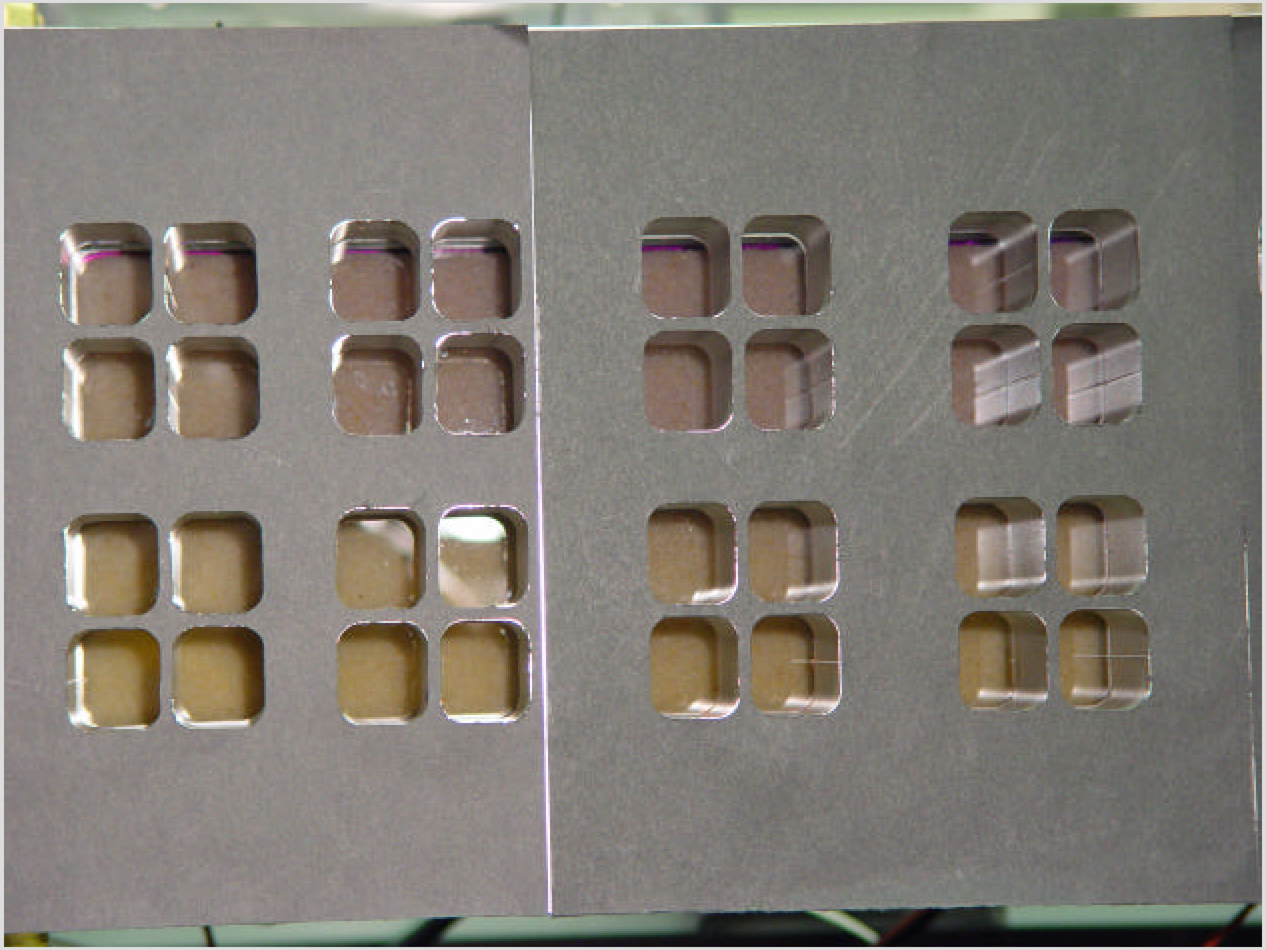

Conclusion

- Buoyancy-driven convection will significantly enhance CO_2 mixing under certain reservoir conditions
- Significantly better understanding of the factors that control fingering convection in porous media is needed
- Improved models of buoyancy-driven convection with $SCCO_2$ in porous media requires comparison with difficult-to-perform experiments
- New pressure cell shows promise for investigating 2-D fingering convection in porous media under supercritical conditions